Proposing safety performance indicators for helicopter offshore on the Norwegian Continental Shelf

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Abstract: Over last 10-years period there has been just one helicopter accident (with no fatalities) in the Norwegian sector of helicopter offshore operations. In this case, safety monitoring cannot be based on the absence of accidents. The main objective of this paper is to suggest a combination of leading and lagging indicators to monitor safety performance for helicopter offshore operations. An approach is described to identify indicators using different perspectives: a Risk Influence Model, the Functional Resonance Analysis Method (FRAM), and lessons learned from previous studies. The approach uses accident and incident data, as well as normal operations (when nothing goes wrong). The suggested indicators were evaluated through observations and interviews/workshop with helicopter operators, air traffic controllers, helicopter deck operators and regulators. The paper discusses the approach and proposes a set of domain specific safety performance indicators. The work was carried out under the Norwegian Helicopter Safety Study 3 (HSS-3).

Keywords: Resilience Engineering, Risk Analysis, Safety Management, Leading and Lagging Safety Indicators

1. INTRODUCTION

1.1. Background

Measurements of safety performance in aviation traditionally rely on lagging indicators such as accident rates, which may be further decomposed to identify particular safety issues. This categorization of accidents has enabled several improvements on specific issues. However, there is a growing concern that this information does not provide the required basis for the prevention of future accidents. The International Civil Aviation Organization (ICAO) recommended the establishment of an effective Safety Management System (SMS) [1]. Indicators are therefore needed to provide an adequate understanding of the current state of the system, and to predict possible future events or consequences of changes; i.e., leading rather than lagging indicators. Yet despite the benefit of a proactive SMS, the aviation industry generally still focuses on the reactive part of safety management.

Helicopter transport is essential for petroleum activities in the North Sea, since there is no other effective way to transport personnel. Over the last 10-years period there has been just one helicopter accident (with no fatalities) in the Norwegian sector of helicopter offshore operations. In this case, monitoring of safety cannot be based on the absence of accidents. This paper presents the results of work carried out under the Helicopter Safety Study -3 (HSS-3) [2], which had the overall objectives to contribute to improve safety and to set a reference standard for methodologies to analyse risk of offshore helicopter transportation. The HSS-3 project was a follow-up of previous studies: HSS-1 (period 1966-1990) [3] and HSS-2 (period 1990-1998) [4]. For the development of indicators, an important mandate for HSS-3 is to use experience from previous helicopter studies [3, 4, 5]. To complement this approach, HSS-3 incorporates development within safety thinking using a resilience engineering perspective to identify safety indicators.

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1.2. Purpose of the paper

The main objective of this paper is to suggest a combination of leading and lagging indicators to monitor safety performance for helicopter offshore operations. An approach is described that identifies indicators, using different perspectives: (1) the Functional Resonance Analysis Method (FRAM), (2) a Risk Influence Model, and (3) lessons learned from previous studies. Data from normal operations (when nothing goes wrong), were used together with accident and incident data. The paper discusses the approach and proposes a set of domain specific safety performance indicators.

1.3. Delimitations

The main focus is the indicators within aviation safety in relation to major accidents, hence excludes occupational accidents. The FRAM method was used for the identification of indicators in relation to a specific scenario landing on helicopter deck. Several publications have described the use of risk influence models [2, 3, 4]. The paper emphasized indicators identified through monitoring normal operations.

2. APPROACH

2.1. Combining perspectives to identify indicators

Different perspectives were used to identify safety indicators as illustrated in Figure 1. The literature survey enabled a theoretical understanding of safety indicators, identification of relevant criteria and indicators from other studies. Resilience Engineering represents an alternative perspective on safety that takes into account successes and failures [6]. Resilience is defined as the intrinsic ability of a system to adjust its functioning prior to, during, or following changes and disturbances, so that it can sustain required operations under both expected and unexpected conditions. Resilience Engineering aims to develop theories, tools and methods to support resilient organizations. The FRAM method is based on resilience engineering principles and was used to identify leading indicators. The HSS-3 RIF model is an update of previous HSS-2 model. The RIF model was explored to identify lagging indicators. In combination with a literature survey, this provided candidates for indicators that were assessed in close consultation with the industry using indicators criteria, leading to a final set of leading and lagging indicators.

2.2. Data gathering

The identification of indicators was based on an iterative process:

- An initial set of indicators was identified based on literature review, application of RIF and FRAM method.
- A workshop assessed indicators against indicator criteria.
- Interviews with operational staff (pilots, engineers, training, helicopter deck, air traffic controllers, petroleum representatives and regulator) assessed indicators against indicator criteria.
- Observations of helicopter landing on helicopter deck during simulator session helped to improve modeling and improved analyst understanding of the context of operations.

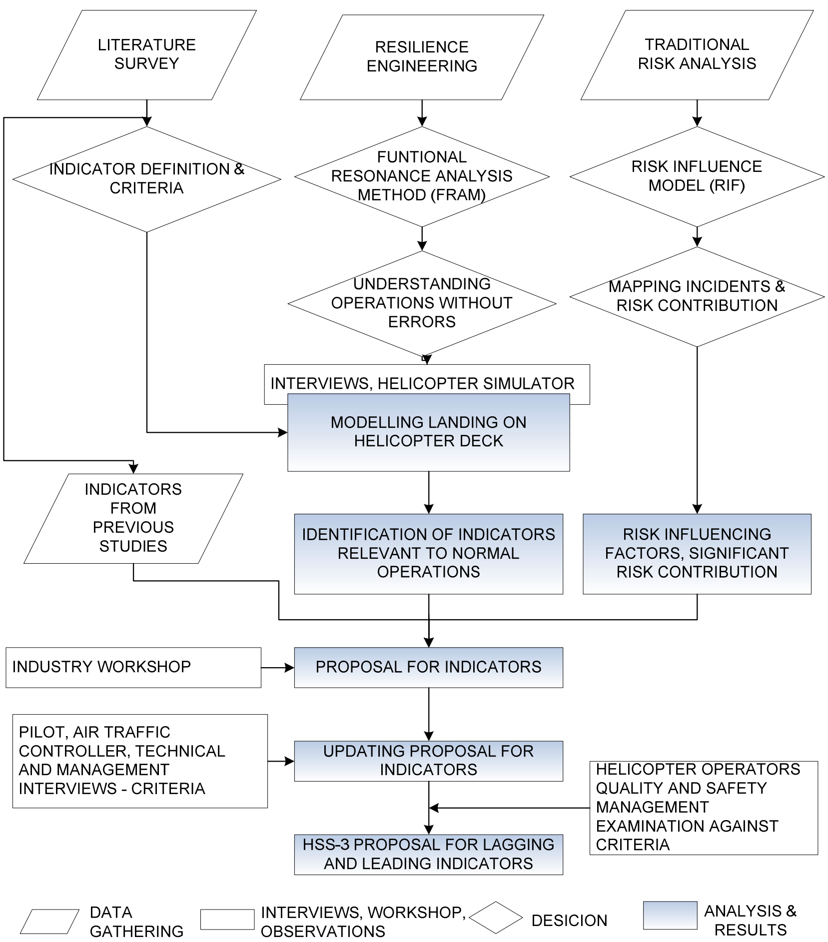
2.3. Important lessons from literature survey

Baseline for HSS-3 was the recommendations in the public report “Helicopter Safety on the on the Norwegian Continental Shelf, Part 2: Trends, objectives, risk influencing factors and recommended measures” [5]. The indicators that can be used to monitor risk were:

- number of deaths per million flight hours;
- number of accidents per million flight hours;

- number of deaths per year due to helicopter transport;
- number of serious accidents and incidents per year or million flight hours;
- number of occurrences per year or million flight hours,
- number of technical and operational reports per year or per million flight hours; and
- subjective risk (questionnaire)

Figure 1: HSS-3 overall approach to propose lagging and leading indicators



Over the last 10-years period there has been just one helicopter accident (with no fatalities) in the Norwegian sector. In addition, changes in regulations contribute to a reclassification of incidents and an increased of number of reports. An increased number of reports do not necessarily provide an indication of poor safety performance. Fatality rate and increased number of reports are therefore not suitable as sole indicators for safety performance. To complement this view, it is necessary to look for accident precursors to assess safety performance. In general, leading indicators are defined as conditions, events or measures that can be used to predict the future occurrence of an event, e.g., as accident precursors. The literature shows that there is no consistency between the definition of indicators and their application [9]. Special attention should therefore be given to the definition of indicators each time they are addressed.

Based on literature review, discussion in international forums and author's experience the following definitions are used:

- Lagging indicators measure results after unwanted events.
- Leading indicators refer to current system status and their interpretation may be used to say something about future performance

The literature presents an extensive list of characteristics for indicators. There is a need for a realistic approach for the selection. The following characteristics are adopted:

- Meaningful: the value can be correlated to accident frequency or consequence, a RIF for the risk model on accidents, or with FRAM functions for the risk model for normal operations.
- Available or affordable: it is possible to gather data with a reasonable cost.
- Reliable: The data should as far as possible be either objective or intersubjectively verifiable.
- Operational: It is possible to use the indicator to identify specific improvement measures in an operational context.
- Ownership: The indicators are “owned” by the personnel which performance is measured.

The Accident Investigation Board/Norway (AIBN) presents a study regarding the relation between concurrent organizational changes and safety [11]. In this study 5 outcome-based and 38 activity-based performance indicators for flight safety were proposed [11, 12]. The development of indicators and determination of importance for flight safety are based on safety audit checklists and discussions with experienced people from the Norwegian and Swedish civil aviation authorities. These indicators are considered as candidates for HSS-3 recommended indicators. Another significant finding in the study showed is that there is a strong focus on learning from rare accidents and failures. There is no tradition to analyze successes (normal operations with no delays) [13]. This trend has changed for flight operations and air traffic management with the introduction of Line Operations Safety Audit (LOSA) and Normal Operations Safety Survey (NOSS) respectively. These safety management tools are mainly based on managing errors and threats.

2.4. Functional Resonance Analysis Method (FRAM)

Resilience Engineering provides a practical basis for the development of systemic models in order to describe the characteristic performance of a system as a whole. It can therefore also be used as the starting point for developing a systemic or functional risk model (FRM). The purpose of a systemic model is to describe the dynamic and non-linear nature of what happens within a system. This should be seen as a complement to the traditional view where accidents are described either as sequences or as concatenation of latent conditions. Hollnagel presents a new method to perform accident investigation and safety assessment, called the Functional Resonance Analysis Method (FRAM) [7].

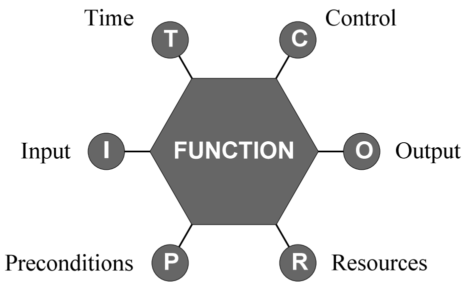
Resilience engineering sees success is as a consequence of the ability of groups, individuals, and organizations to anticipate the changing shape of risk before damage occurs; failure is simply the temporary or permanent absence of that. Adopting this view means that there is a need for models that can represent the variability of normal performance and methods that can use this both to provide more comprehensive explanations of accidents and to identify the possible risks. The helicopter safety study adopts this view to identify leading indicators.

In its present form, FRAM comprises the following five steps [8]:

Define the purpose of the analysis, since FRAM can be used for both accident investigation and safety assessment.

Identify and describe system functions. The result of the second step is the model. Every function can be characterized by six basic aspects: Input (I, that which the function uses or transforms), Output (O, that which the function produces), Preconditions (P, conditions that must be fulfilled to perform a function), resources (R, that which the function needs or consumes), Time (T, that which affects time availability), and Control (C, that which supervises or adjusts the function). A FRAM function is shown in Figure 2.

Figure 2: The six aspects of a FRAM function

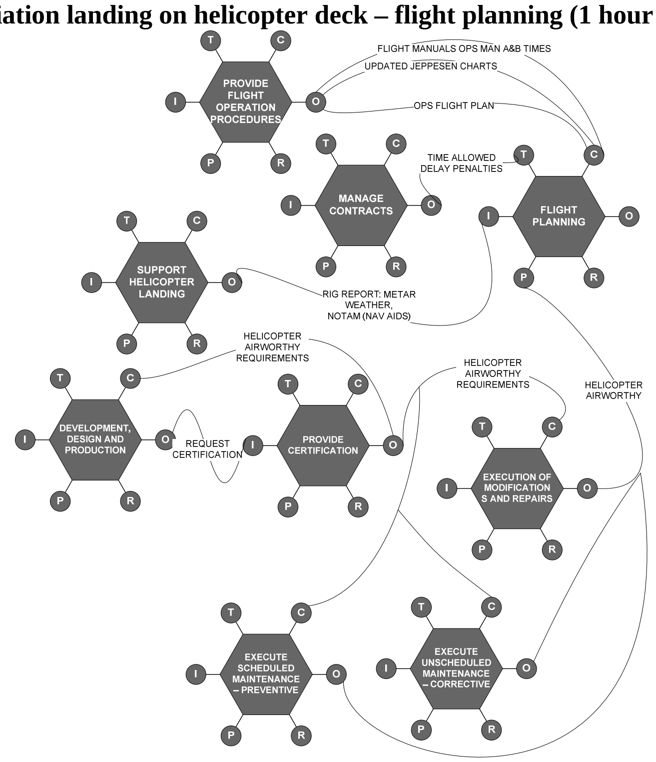


Assess and evaluate the potential variability of each function. This evaluation should be integrated with the retrospective information extracted from accident databases to the extent that data are available.

Identify functional resonance by means of instantiations. An instantiation illustrates aspects and the potential links among the functions in a defined context [10]. Figure 3 shows an instantiation for approach planning. The aim of this step is to determine the possible ways in which the variability from one function could spread in the system and how it may combine with the variability of other functions. This may result in situations where the system loses its capability safely to manage variability. The propagation may be both indirect via the effects that the variability may have on the general conditions or direct via the output from a function.

Identify effective countermeasures or barriers that can be introduced in the system. In FRAM, prospective countermeasures aim at dampening performance variability in order to maintain the system in a safe state. But it is consistent with the principle of Resilience Engineering to consider also measures that can sustain or amplify functional resonance that leads to desired or improved outcomes. Besides recommendations for countermeasures or barriers, FRAM can also be used to specify recommendations for the monitoring of performance and variability, in order to be able to detect undesired variability at an early stage. Performance indicators may thus be developed for individual functions and for the couplings among functions.

Figure 3: Instantiation landing on helicopter deck – flight planning (1 hour before departure)



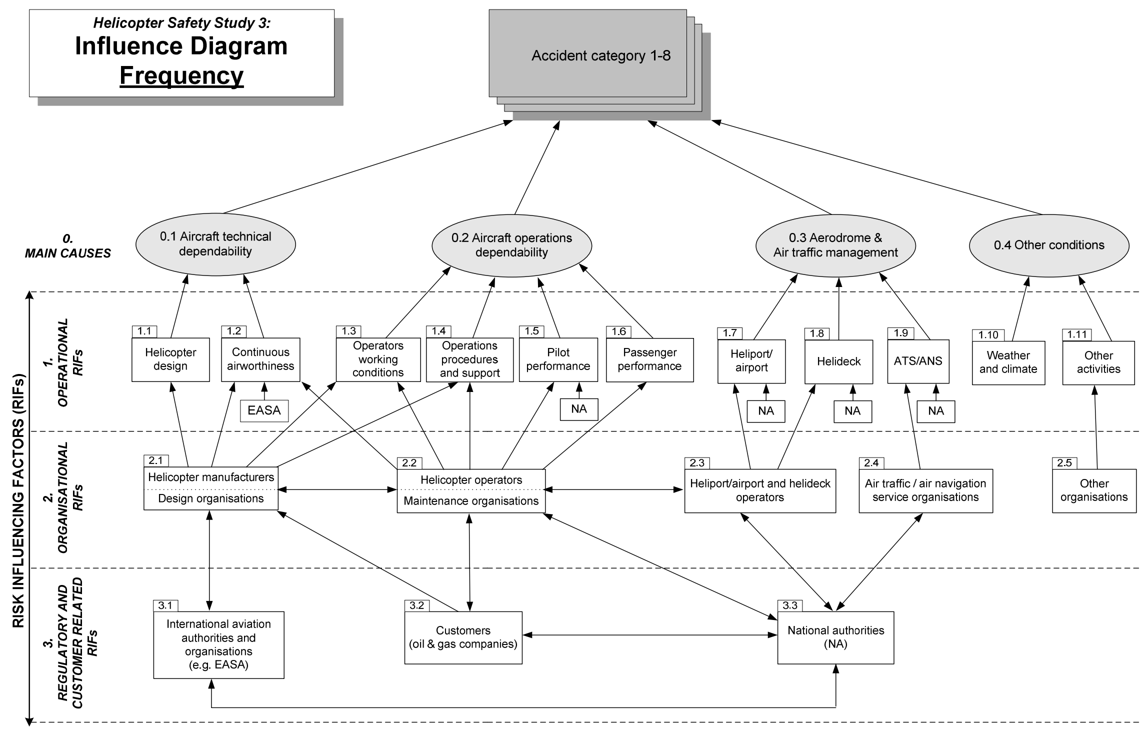
2.5. Risk Influence Modeling (RIF)

The risk influence model in the HSS-3 project is an update of the model developed in the previous helicopter safety study [4]. This approach assumes that accidents and incidents can be described as the result of cause-effect relations, sometimes as a single cause-effect chain but more often as a combination of multiple cause-effect chains.

The risk influence model is based on a number of Risk Influencing Factors (RIFs) arranged in influence diagrams. A RIF is defined as a set of conditions that influence the risk, either positively or negatively. The RIFs are likely to have a varying degree of importance for the different categories of accidents. Eight different accident categories are defined in the model. These categories are: accident by take-off or landing on heliport, accident by take-off or landing on helicopter deck, accident following critical aircraft system failure during flight, near miss or mid-air collision with other aircraft, collision with terrain, sea or building structure, accident exposing passengers inside the helicopter, accident exposing passengers outside the helicopter and other/unknown (i.e. lightening). The status of a RIF may be improved by specific actions or become worse due to changes and threats.

The RIFs are split into two categories; risk frequency influencing factors (as shown in Figure 4) and risk consequence influencing factors, and are organized in three levels. Operational RIFs (Level 1) are risk influencing factors related to activities directly influencing the risk and that are necessary to provide safe helicopter operations on a day-to-day basis. These activities include conditions related to technical dependability, operational dependability, provision of necessary external services and surroundings. Organisational RIFs (Level 2) are defined as risk influencing factors related to the organizational basis, support and control of running activities in the helicopter transport. These factors are related to helicopter manufacturers or design organizations, helicopter operators, maintenance organizations, air traffic and navigation services, heliport and helicopter deck operators. Regulatory and customer related RIFs (Level 3) are defined as risk influencing factors related to requirements and controlling activities from international organizations, authorities and customers.

Figure 4: Risk Influence Model HSS-3 for the frequency of accidents



3. MAIN RESULTS

3.1. Leading indicators identified applying FRAM

The scenario described in this paper is an approach to and landing on a floating platform during night with good visibility and no unusual events. Results from the application of FRAM referred to the five steps described in section 2.2. In the first step FRAM was used as safety assessment looking into normal operations to identify relevant indicators. In the second step a corpus of 21 functions was identified as relevant for the scenario landing on helicopter deck, e.g., Table 1.

Table 1: Example of FRAM functions for scenario landing on helicopter deck

Landing on helicopter deck FRAM functions	
Manage contracts	Manage competence
Perform weight & balance calculations	Manage procedures
Approach planning	Fix approach on GPS
Do pre-landing preparations	Arrive to minimum descend
Approach near by obstruction	Establish visual
Decide approach type (see Table 2)	Verify position
Land	Support helicopter landing

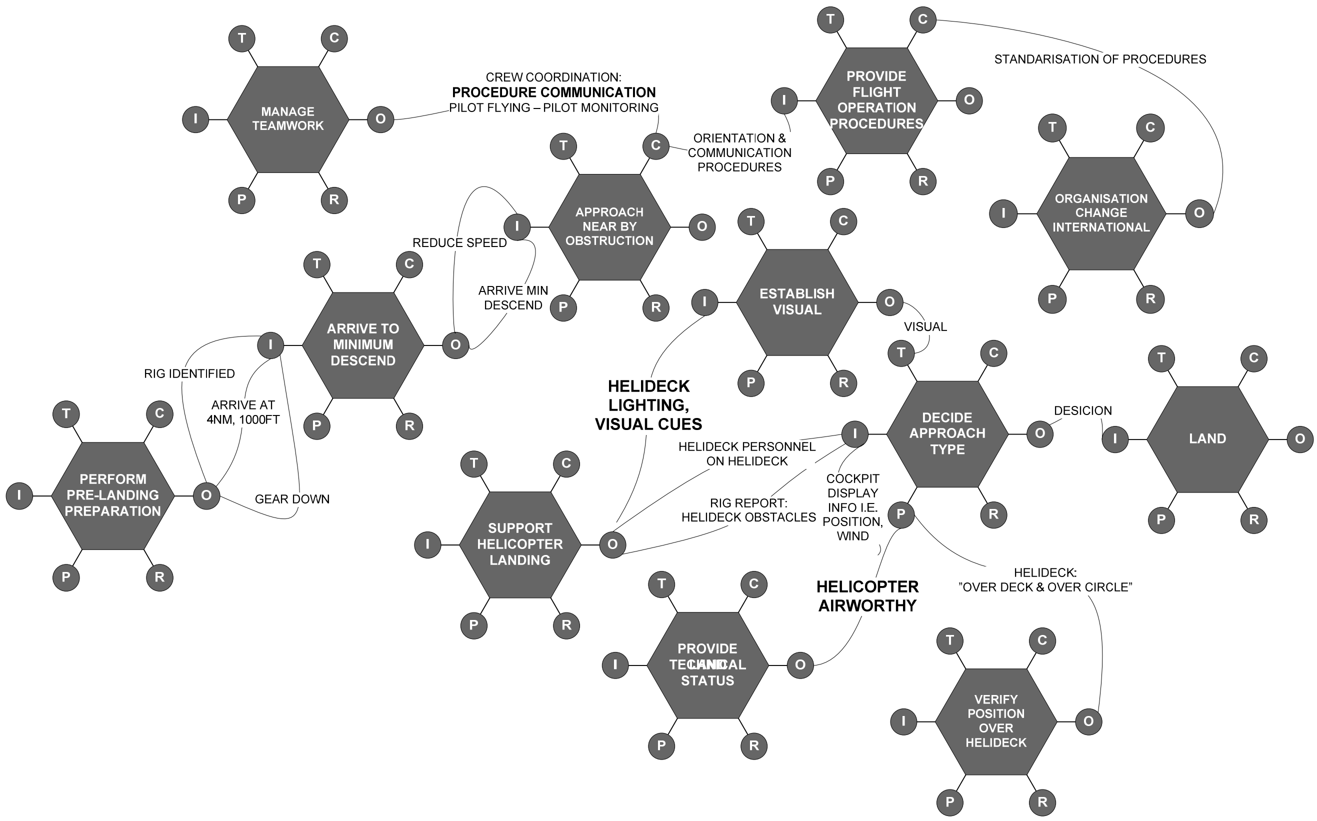
Each function was characterized in terms of six aspects (an example is shown on table 2). The granularity of the description of functions was based on iterative assessment of the scenario and the functions between the analyst and pilot.

Table 2: FRAM function characterization

FRAM Function	**Decide Approach type**
Input	Helicopter deck personnel on helicopter deck
Input	Helicopter deck obstacles report
Input	Cockpit display information: wind and position
Output	Decision
Precondition	Helicopter airworthy
Precondition	Company message “ Over deck & over circle”
Time	Visual
Control	Approach procedures

The third step was the assessment of the potential variability for each singular function. Landing on helicopter deck was analyzed in relation to landing on fixed and floating oil and gas installation during day and night. In this way, it was possible to determine variability related to normal operations. The fourth step is the determination of the ways in which variability is spread through the system. Instantiations were used to illustrate the combinations of variability. Then indicators were determined based on significant combinations of variability (bold letters illustrated on Figure 5).

Figure 5: FRAM instantiation for landing on helicopter deck during night



It was necessary to have operational indicators (shown in Table 3). This was achieved through discussions with operational and management personnel.

Table 3: Example of indicators identified for normal operations

Indicator	Operationalization
Helicopter airworthy	Indicators related to maintenance performance, Vibration Health Monitoring and Minimum Equipment List
Quality of communication helicopter crew and helicopter deck personnel	There are individual differences in relation to installation type i.e. fixed or floating. Use of observations to provide a qualitative evaluation.
Procedures quality and compliance	Use of audits and/or observations to provide an assessment of procedures revision and compliance
Manage contracts – use of penalties	Number of free days that have been negotiated, use of overtime
Visual references	Helicopter deck status in relation to regulation and recognized guidelines

3.2. Lagging indicators identified using RIF approach

The indicators are based on number of incidents and are mainly related to the operational level. Examples of identified indicators are:

- Technical RIF: Windshield cracking, chip warning, oil leakage detected by walk-around
- Operational RIF: Overload of cargo, incorrect marking or improper handling of dangerous goods, fuelling event, wrong charts in flight folder
- Helicopter deck RIF: Crane or other obstacles on rig near to helicopter deck, incorrect helicopter deck position, incorrect information of pitch/roll/heave from moving helicopter decks
- Weather and other RIF: Incorrect weather information, bird strikes

4. DISCUSSION AND CONCLUDING REMARKS

Helicopter safety is a result of something that the system does and not a passive property of the system. Safety is a dynamic characteristic and the result of interaction between several organizations. This view guides the indicators that are identified in the study. Each method represents different ways of understanding, it is necessary to be aware of their advantages and limitations. The paper demonstrates how a combination of several approaches provides a set of lagging and leading indicators. Since we are addressing a dynamic characteristic, it is recommended periodically to review the indicators to see if they are still relevant or whether new indicators should be considered.

The literature review show that the majority of indicators are selected from check lists or because they are easy to collect. This approach does not necessarily support indicators relevance towards safety. The FRAM modeling provides a more dynamic approach to helicopter operations. The use of instantiations enables to illustrate how variability spreads and which variability is significant to a successful landing. The main advantage of FRAM is that this approach considers the influence of the context on actual performance. Indicators identified using FRAM are leading, these indicators show a correlation to a successful operation. Indicators identified using RIF model are mainly lagging, these indicators are based on incidents and accidents information. The RIF model provides an static picture of the overall helicopter offshore operations. The recommended set of indicators represents a combination of quantitative and qualitative data. Experience from previous studied show that quantitative information does not provide enough information towards the quality aspect. This shortcoming is compensated emphasizing the importance of observations and use qualitative data.

This study represents a step forward from mainly learning from failures to consider also normal operations without failures. This approach has helped to identify alternative indicators. The identification of indicators using FRAM and the modeling enhanced understanding of the system. The indicator discussions with the industry helped to identify recommended measures to improve safety relevant to actual performance. The RIF approach allows a perspective of helicopter performance during the last 30 years. The FRAM approach represents a step forward in using new methods to improve aviation safety. While RIF method is widely recognized for risk assessment. The FRAM approach will require more applications to demonstrate its capability and have wider acceptance within the safety community.

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